THE

ONTARIO WATER RESOURCES

COMMISSION

# EFFECTS OF ACID MINE WASTES

# on the

# CHEMISTRY AND ECOLOGY

# of

# LAKES IN THE MANITOUWADGE CHAIN

# DISTRICT OF THUNDER BAY

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## SUMMARY AND CONCLUSIONS

This report presents the findings of an extensive study of water pollution resulting from the base-metal mining and milling industry in the Manitouwadge area.

The study has shown serious impairment of water quality and associated effects on aquatic life of several lakes in the Black River System. The lakes most seriously impaired were Mose and Manitouwadge which receive the respective waste discharges from Noranda Mines Limited (Geco Division) and Willroy Mines Limited.

In Mose Lake, the continuous input of wastes of high dissolved solids content has resulted in the establishment of a density gradient with depth which prevents the lake water from mixing. As a result, conservative components of the wastes have become trapped and concentrated to critical levels in the bottom waters of the lake. Specifically, the problems identified in Mose Lake were:

1) acid generation and pH depression
2) total de-oxgenation of waters below the twenty foot level
3) toxic concentrations of ammonia, zinc, copper and iron
4) excessive nitrogen enrichment
5) exceptionally high concentrations of dissolved solids, particularly sulphates
6) major accumulations of zinc, copper, lead and iron in the lake sediments
7) total elimination of bottom-dwelling macro-invertebrates, an important link in the aquatic food chain.

While a density gradient had not materialized in Manitouwadge, the lake had to a lesser extent, the same water quality problems as found in Mose Lake. The downstream lakes; Little Manitouwadge, Little Mose, Kaginu and Agonzon were all discovered to contain concentrations of dissolved solids, metals and ammonia which were considerably higher than background levels in the reference lakes, Wowun and Morley.

The study has demonstrated the need for major improvements in the methods of treating wastes from the mining and milling industry at Manitouwadge. The prospect of re-establishing viable populations of indigenous aquatic life in the affected waters offers a major challenge to the industry. In order to succeed it will be necessary to restore the chemical quality of the receiving waters to baseline conditions, baseline being defined as conditions which exist in the reference lakes Wowun and Morley. Specifically, it will be necessary to:

1) eliminate ammonia losses to Mose Lake either by treatment or the use of an alternative neutralizing agent
2) control metals losses to essentially background concentrations
3) prevent further discharge of oxidizable sulphuritic wastes to lakes Manitouwadge and Mose
4) provide pH adjustment so that the pH of the wastes will remain stable within the prescribed limits (6.5 to 8.5) at the point of discharge
5) provide treatment to bring about a substantial reduction in the loading of sulphates and other dissolved solids to the receiving waters

# INTRODUCTION

Owing to public concern over a decline in fishing success and suspected pollution of the Manitouwadge Chain of Lakes, district staff of the Department of Lands and Forests at Manitouwadge carried out studies in 1968 which demonstrated water quality impairment in several lakes downstream from the Manitouwadge mining industry. The report raised questions concerning the effect of mine wastes on the production of sport fish species which prompted further limnological studies of the Manitouwadge Lakes by the Biology Branch of the OWRC during 1970. The object of the Commission's studies was to determine in a more definitive manner the nature, degree and extent of mine waste contamination in the Manitouwadge Lakes in order to elucidate the waste abatement requirements necessary to restore and protect viable populations of game fishes. It was recognized that the attainment of water quality suitable for protection of fish would also ensure water quality suitable for most, if not all of the other recognized water uses.

## GENERAL DESCRIPTION OF MINING OPERATIONS

A major base-metal mining camp was established in the Township of Gemmell near Manitouwadge in 1957 when Willroy Mines Limited and the Geco Division of Noranda Mines Limited initiated mining and milling operations. Both developments involve conventional underground mining and surface milling techniques for the recovery and concentration of copper, lead and zinc values from their respective metallic sulphides-chalcopyrite, galena and sphalerite.

During 1970, these operations included the mining and milling of approximately 1300 tons of ore daily at the Willroy operation and a further 5000 tons per day at the Noranda mine. The only major difference in milling procedure between the two companies during 1970 involved the use of anhydrous ammonia for pH adjustment in the copper and zinc circuits at Noranda Mines Limited. Willroy Mines Limited was utilizing lime as a neutralizing agent.

Following treatment in separate tailings impoundment facilities, the decants of waste waters resulting from these operations flow to lakes of the Black River system. Contaminants from the Willroy mining and milling operation are directed to Manitouwadge Lake via Willroy Creek. The decant from Noranda Mines Limited discharges to Mose Lake through a drainage channel referred to in this report as Noranda Creek. Fox Creek which flows to Manitouwadge Lake also carried seepage contaminants originating from the Noranda impoundment facilities.

Domestic wastes from Manitouwadge are collected for conveyance to an adjacent watershed. Thus, with the exception of a small townsite of Willroy Mines Limited which is serviced by septic tanks, the only domestic wastes which have access to the Manitouwadge Chain of Lakes are those which originate from within the mines and mills.

## DESCRIPTION OF STUDY AREA

The study area shown in Figure 1 consists of a chain of lakes forming part of or draining to the Black River system in the District of Thunder Bay. The Black River has its origin north of the Improvement District

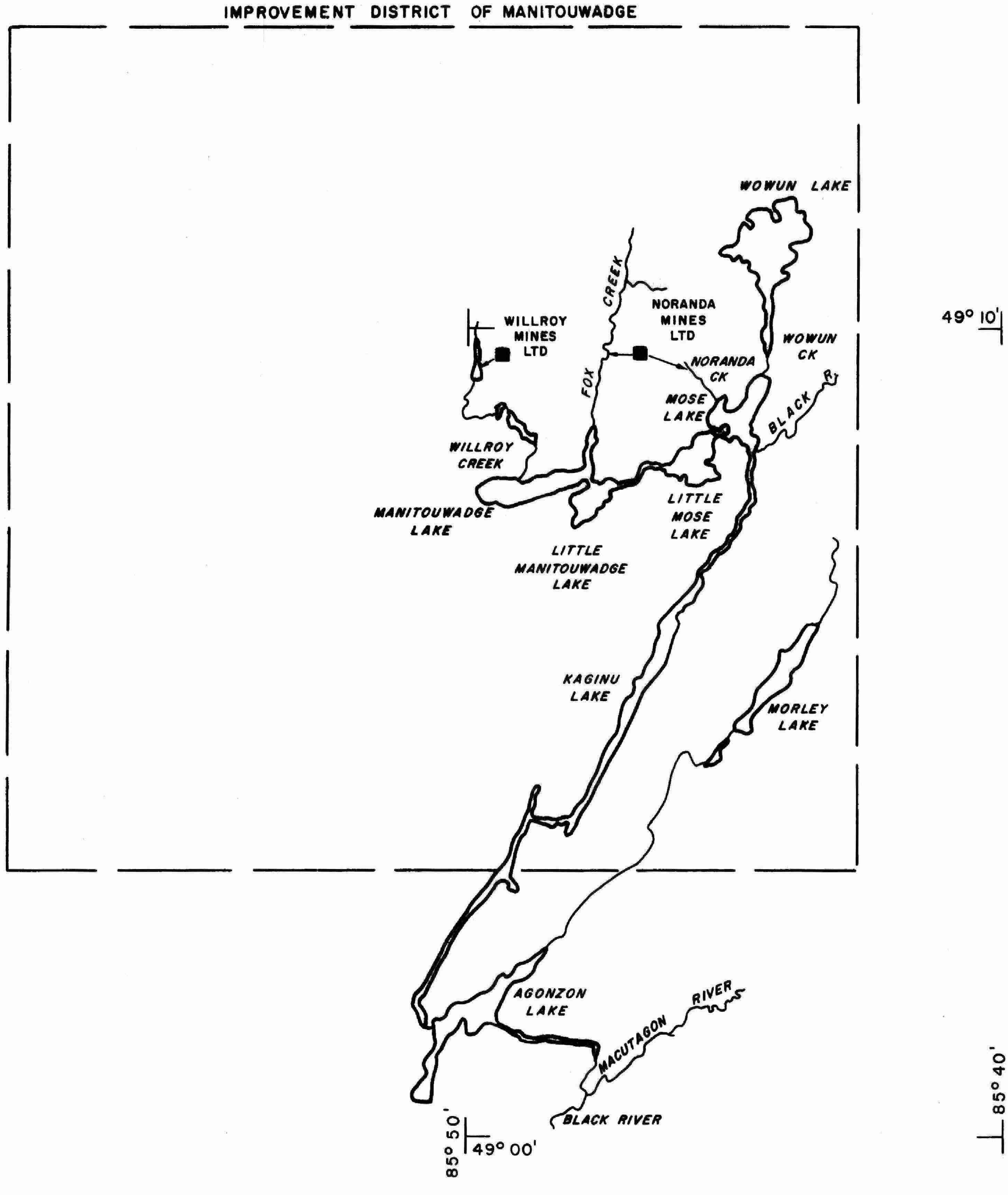


FIGURE I

MANITOUWADGE CHAIN OF LAKES

of Manitouwadge and flows in a general southerly direction to its confluence with the Pic River which in turn discharges to Lake Superior near Heron Bay.

The Improvement District of Manitouwadge, which encompasses the townships of Mapledoram, Gemmell, Leslie and Gertrude, is situated approximately 35 miles north of Highway 17 via Highway 614.

Two reference lakes, Wowun and Morley, were selected for the investigation as being representative of conditions in uncontaminated lakes on the Manitouwadge Chain. Wowun Lake is the largest of the study lakes, occupying a surface area of 600 acres with a maximum depth of 43 feet. Morley Lake is one of the smaller lakes included in the investigation, having a surface area of 220 acres and a depth of 14 feet. Both Wowun and Morley occupy headwater positions and as such are limited in water exchange to the drainage of their own small basins. No mill wastes have entered either lake.

The main body of Manitouwadge Lake covers a surface area of 345 acres and reaches a maximum depth of 32 feet. Like the reference lakes, Manitouwadge Lake occupies a headwater position and therefore has only limited water exchange.

Little Manitouwadge Lake is basically a restriction and subsequent widening of Manitouwadge Lake. It is the smallest of the study waters with a surface area of 146 acres and depths of 10 feet or less. Similarly, Little Mose Lake is a small shallow bog lake occupying a surface area of 250 acres with depths of 8 feet or less. Both lakes are downstream from Manitouwadge Lake and are contaminated with mining wastes.

Mose Lake is 250 acres in area with a maximum depth of 36 feet. Little Mose Lake empties into Mose Lake as does the Black River and the overflow from Wowun Lake.

The lakes Kaginu and Agonzon, by virtue of their downstream location, are both subject to the influence of mine waste contaminants displaced from Mose Lake. Kaginu is a long and narrow lake which covers a surface area of 322 acres with depths of 19 feet or less. Agonzon, the last lake of the chain, has a surface area of 360 acres with a maximum depth of 29 feet.

For ease of reference, Table 1 below provides a summary of the areas and maximum depths of the study lakes.

Table 1. Morphometric characteristics of the Manitouwadge Lakes.

| | Surface area (acres) | Maximum depth (feet) |
|---|---|---|
| Morley Lake | 232 | 14 |
| Wowun Lake | 600 | 43 |
| Manitouwadge Lake | 330 | 32 |
| L. Manitouwadge Lake | 146 | 10 |
| L. Mose Lake | 216 | 8 |
| Mose Lake | 250 | 36 |
| Kaginu Lake | 322 | 19 |
| Agonzon Lake | 360 | 29 |

## METHODS

Field work for the present study commenced on February 10 during conditions of ice cover and terminated on November 3 just prior to lake freeze-up. A total of thirteen sampling runs were completed, ten during the ice-free months from May to November.

Main emphasis of the study was placed on detailed examination of the chemistry and biology of two uncontaminated reference lakes and the six lakes exposed to mine wastes. At the same time, the chemical quality of the three waste bearing streams - Willroy, Fox and Noranda - and a reference stream, Wowun was examined as was that of the Black River upstream and below the Manitouwadge Lakes.

## On-the-spot Determinations

On-site measurements of water transparency, temperature, pH and conductivity were taken at each of the lake stations. Water transparency was measured with an eight-inch Secchi disc. Temperature readings were made using a telethermometer. Dissolved oxygen concentrations were determined using the azide modification of the Winkler method. pH and conductivity measurements were read from field meters.

## Water Chemistry

Water samples for detailed chemical analyses were secured with a Kemmerer water sampler. Analyses for heavy metals were made on samples collected in plastic containers and preserved with nitric acid at the time of collection. All other water chemistry determinations were carried out on unpreserved samples shipped in glass containers. The chemical analyses were conducted at OWRC laboratories.

## Sediment Chemistry

Sediment samples were obtained with an Ekman dredge. The top layer of mud was scraped into a glass jar, after which the sample was air dried and submitted to the OWRC laboratory at Toronto for metals analyses. Fusion techniques were used for sample preparation and the metal values were determined by atomic absorption.

## Fish Flesh Chemistry

Fish samples were taken from the lakes under study by staff of the Department of Lands and Forests. These specimens were quick-frozen and forwarded to the OWRC laboratory for heavy metal scans.

## Bottom Fauna

Bottom fauna samples were secured with a 9 x 9 inch Ekman dredge. After noting the characteristics of the sediment, the sample was washed through a 24-mesh-per-inch (0.0256 inch openings) sieve and the organisms were separated and removed from extraneous materials. All samples were preserved in ethanol and retained for subsequent identification and enumeration.

## Phytoplankton

Composite phytoplankton samples were taken from the euphotic zone at each of the study sites. The euphotic zone was estimated as being twice the Secchi disc reading. Samples were preserved with Lugol's iodine and submitted to the main laboratory of the Biology Branch for identification and enumeration.

# FINDINGS

## Water Quality

While it was beyond the scope of this investigation to undertake a materials balance for the various chemical constituents of mining wastes, a task which would have required extensive hydrological data, monitoring of the waste input streams was carried out in order to relate the chemical quality of the study lakes to the sources of contaminants. Water quality of the Black River was also examined above and below the study lakes to determine the

downstream location at which restoration of reference water quality was achieved.

Indication of the quality of water being discharged to the study lakes by way of the three contaminated creeks, Willroy, Fox and Noranda, is given in Table 2. For purpose of comparison this table indicates the chemical quality of Wowun, an uncontaminated creek which flows into Mose Lake. The grossly impaired nature of Willroy and Fox creeks and especially Noranda Creek is readily evident from these data. An even better appreciation of the degree to which the Manitouwadge Lakes are being loaded with contaminants is gained by examining the volume of wastes being discharged. Willroy Mines Limited discharges approximately 0.75 million gallons of water daily to Willroy Creek and operations at Noranda Mines Limited result in a daily waste decant of approximately 2.5 million gallons. The waste water decant to Willroy Creek receives approximately 1:1 dilution before reaching the monitoring point whereas little or no dilution occurs in Noranda Creek. This accounts for some of the difference in waste concentrations between Willroy Creek and Noranda Creek. The only significant difference in milling procedure between the two operations related to the use at Noranda Mines Limited of anhydrous ammonia for pH adjustment, a practice which was not being followed at Willroy Mines Limited during the survey period. This accounts for the staggering difference in free ammonia levels in Willroy Creek (.56 ppm) and Noranda Creek (21.13 ppm).

Comparative data on water quality of the eight study lakes is provided in Table 3. Assuming that, prior to mining activity all of those lakes were similar in chemical compositon to that of the uncontaminated Wowun Lake and Morley Lake, the data demonstrate marked changes

Table 2. Water quality of Willroy, Fox and Noranda; three contaminated creeks and Wowun; a reference creek, which discharge to the Manitouwadge Lakes. Values listed are the average concentration in parts per million. The number of measurements is indicated in brackets.

| | Wowun Creek | Willroy Creek | Fox Creek | Noranda Creek |
|---|---|---|---|---|
| Dissolved solids | 125(3) | 746(2) | 180(2) | 1588(2) |
| Sulphates (as $SO_4$) | 8(4) | 367(3) | 196(3) | 1107(3) |
| Free ammonia (as N) | .17(4) | .56(4) | .99(4) | 21.13(4) |
| Hardness (as $CaCO_3$) | 159(3) | 380(3) | 202(3) | 747(3) |
| Alkalinity (as $CaCO_3$) | 78(4) | 7.3(4) | 38(4) | 10.8(4) |
| Acidity (as $CaCO_3$) | 1(4) | 3.3(4) | 14.8(4) | 85.5(4) |
| Iron (as Fe) | .06(4) | .42(4) | 7.9(4) | 23.9(4) |
| Zinc (as Zn) | .01(4) | .69(4) | .70(4) | 3.41(4) |
| Copper (as Cu) | 0.0(4) | .02(4) | 0.0(4) | .26(4) |

in the chemistry of Manitouwadge and Mose Lake and significant impairment of each of the downstream lakes. Comparison of the similarities in chemical quality of the contaminated streams (Table 2) with the chemical quality of Manitouwadge Lake and Mose Lake (Table 3) add unquestionably to the credibility of the aforementioned assumption.

Critical water chemistry changes in Manitouwadge Lake and Mose Lake include gross alteration of their ionic composition, increased acidity, dissolved oxygen depletion (see Table 4) and elevations of heavy metals and ammonia content to acutely toxic levels. The chemical quality of both lakes is such that neither would be capable of supporting most of their indigenous fauna.

High metals and ammonia content persist throughout all of the downstream lakes. Little Manitouwadge Lake, Little Mose Lake, Kaginu Lake and Agonzon Lake all contained concentrations of these contaminants which would be expected to exert sub-lethal effects on aquatic communities. These lakes probably could support resident populations of fish but poor production would be expected.

Early in the investigation it became evident that restoration of reference water quality was incomplete at Agonzon Lake. In order to discover the point at which normal water quality returned, three sampling stations were added, their locations being Station 1, the Black River reference upstream from all contaminants; Station 2, Black River at Highway 614 and Station 3, Black River at Highway 17. Stations 2 and 3 were located approximately 15 and 60 river miles below Agonzon Lake, respectively.

Table 5 provides the results of chemical tests conducted on water samples secured from the three Black River sampling stations. These data show that restoration of baseline quality

Table 3. Chemical properties of the surface waters of eight lakes in the Manitouwadge Chain. All values are recorded as the average concentration in parts per million. The number of measurements is provided in brackets.

| | Wowun Lake | Morley Lake | Manitouwadge Lake | Little Manitouwadge Lake | Little Mose Lake | Mose Lake | Kaginu Lake | Agonzon Lake |
|---|---|---|---|---|---|---|---|---|
| Dissolved solids | 101(3) | 108(1) | 303(11) | 221(4) | 212(4) | 265(11) | 184(4) | 161(4) |
| Sulphates (as $SO_4$) | 9.3(3) | 8(1) | 146(12) | 102(5) | 97(5) | 130(12) | 80(5) | 59(5) |
| Free ammonia (as N) | .07(3) | .03(1) | .30(12) | .17(5) | .19(5) | 2.6(12) | .78(5) | .74(5) |
| Hardness (as $CaCO_3$) | 81(3) | | 240(8) | 137(3) | 137(3) | 162(8) | 118(3) | 98(3) |
| Alkalinity (as $CaCO_3$) | 71(3) | 49(1) | 50(12) | 47(5) | 50(5) | 43(12) | 46(5) | 39(5) |
| Acidity (as $CaCO_3$) | 1.3(3) | 0(1) | 4(12) | 2.6(5) | 2(5) | 4.3(12) | 2.6(5) | 2.5(5) |
| Iron (as Fe) | .18(3) | .03(1) | 1.88(12) | 1.37(5) | 1.09(5) | 1.50(12) | .82(5) | .90(5) |
| Zinc (as Zn) | .02(3) | .05(1) | .54(12) | .29(5) | .25(5) | .43(12) | .18(5) | .20(5) |
| Copper (as Cu) | 0.0(3) | .01(1) | .023(12) | .014(5) | .012(5) | .03(12) | .022(5) | .013(5) |

Table 4. Vertical and seasonal changes in the temperature and dissolved oxygen profiles of Manitouwadge Lake and Mose Lake, 1970.

| Date | MANITOUWADGE LAKE | | | | MOSE LAKE | | | |
|---|---|---|---|---|---|---|---|---|
| | 0' | 10' | 20' | 30' | 0' | 10' | 20' | 30' |
| **Dissolved Oxygen (ppm)** | | | | | | | | |
| 10.2.70 | 8 | 7 | 7 | 7 | 6 | 6 | 1 | <1 |
| 18.3.70 | 9 | 7 | 5 | 4 | 6 | 4 | 3 | 0 |
| 15.4.70 | 8 | 6 | 5 | 5 | 7 | 3 | 3 | 4 |
| 12.5.70 | 8 | 9 | 10 | 10 | 10 | 10 | 1 | 1 |
| 26.5.70 | 9 | 9 | 9 | 9 | 8 | 9 | 2 | <1 |
| 12.6.70 | 9 | 9 | 8 | 7 | 8 | 9 | 1 | 0 |
| 23.6.70 | 8 | 8 | 8 | 6 | 8 | 8 | 0 | 0 |
| 18.7.70 | 8 | 8 | 7 | 3 | 9 | 8 | 0 | 0 |
| 30.7.70 | 6 | 6 | 6 | 2 | 6 | 6 | 0 | 0 |
| 13.8.70 | 8 | 8 | 6 | 2 | 7 | 7 | 0 | 0 |
| 26.8.70 | 7 | 5 | 5 | 1 | 7 | 5 | 0 | 0 |
| 5.10.70 | 8 | 7 | 7 | 7 | 8 | 7 | 0 | 0 |
| 2.11.70 | 8 | 7 | 7 | 7 | 7 | 7 | 5 | <1 |
| **Temperature (°F)** | | | | | | | | |
| 10.2.70 | 32 | 36 | 36 | 36 | 32 | 35 | 37 | 38 |
| 18.3.70 | 32 | 34 | 36 | 39 | 32 | 37 | 38 | 38 |
| 15.4.70 | 33 | 36 | 38 | 38 | 32 | 37 | 37 | 37 |
| 12.5.70 | 39 | 39 | 39 | 39 | 39 | 39 | 38 | 37 |
| 26.5.70 | 49 | 49 | 47 | 44 | 50 | 50 | 39 | 35 |
| 12.6.70 | 64 | 64 | 52 | 44 | 64 | 64 | 40 | 38 |
| 23.6.70 | 67 | 66 | 64 | 54 | 66 | 64 | 52 | 44 |
| 18.7.70 | 69 | 66 | 63 | 49 | 68 | 65 | 46 | 40 |
| 30.7.70 | 72 | 69 | 66 | 56 | 70 | 68 | 55 | 45 |
| 13.8.70 | 72 | 70 | 66 | 49 | 73 | 64 | 45 | 40 |
| 26.8.70 | 62 | 61 | 61 | 52 | 61 | 61 | 52 | 42 |
| 5.10.70 | 49 | 48 | 48 | 45 | 48 | 48 | 48 | 42 |
| 2.11.70 | 42 | 42 | 42 | 42 | 39 | 41 | 42 | 42 |

Table 5. Water quality of the Black River upstream and below the sources of mine wastes. Values listed are the average concentration in parts per million. The number of determinations is provided in brackets.

| | Black River No. 1 | Black River No. 2 | Black River No. 3 |
|---|---|---|---|
| Dissolved solids | 135 (3) | 163 (3) | 138 (1) |
| Sulphates (as $SO_4$) | 8 (4) | 25 (4) | 14 (1) |
| Free ammonia (as N) | .04 (4) | .14 (4) | .16 (1) |
| Hardness (as $CaCO_3$) | 67 (3) | 123 (3) | 82 (1) |
| Alkalinity (as $CaCO_3$) | 83 (4) | 95 (4) | 64 (1) |
| Acidity (as $CaCO_3$) | 4 (4) | 1 (4) | 5 (1) |
| Iron (as Fe) | .15 (4) | .09 (4) | .20 (1) |
| Zinc (as Zn) | .005 (4) | .012 (4) | 0.0 (1) |
| Copper (as Cu) | 0.0 (4) | .018 (4) | 0.0 (1) |

is incomplete at the Highway 614 crossing but satisfied for the most part at Highway 17. Even at the latter location, however, high ammonia values persisted. Dilution provided by the inflowing tributaries Macutagon, Mobart, Bearhead, Cedar and Swede would account for the recovery observed.

## Comparison between Manitouwadge and Mose

In the preceding section, the surface water quality of the study lakes was examined in order to relate changes in their quality to the points of waste inputs. One interesting feature of these data (Table 3) was the poor quality of the surface waters of Manitouwadge, Little Manitouwadge and Little Mose in comparison to the surface water quality of Mose, Kaginu and Agonzon. The reverse situation would be expected since Mose Lake receives nearly four times the volume of wastes that discharge to Manitouwadge Lake. The reason for this apparent discrepancy can be seen in Table 6 which explores the vertical quality of the two lakes. While the water chemistry of Manitouwadge Lake is fairly consistent throughout the water column, a marked chemical gradient occurs with depth in Mose Lake. If one examines the seasonal changes in the vertical composition of sulphates in these lakes (Table 7), it will be noted that Manitouwadge Lake experiences the normal seasonal processes of stratification and destratification. Through these processes, contaminants which enter the lake are mixed throughout the entire water mass so that some of the wastes would leave the lake as overflow. In contrast, the seasonal pattern of sulphate distribution in Mose Lake demonstrates that the lake is meromictic, that is to say, the lake remains in a continual state of stratification. This condition develops when dissolved solids create a gradient of density

Table 6. Comparison of the vertical chemical properties of Manitouwadge Lake and Mose Lake. Values recorded indicate the average concentration derived from twelve measurements from February to November, 1970.

| | Manitouwadge Lake | | | | Mose Lake | | | |
|---|---|---|---|---|---|---|---|---|
| | 0' | 10' | 20' | 30' | 0' | 10' | 20' | 30' |
| Dissolved solids | 303 | 308 | 349 | 393 | 265 | 507 | 1158 | 1494 |
| Sulphates (as $SO_4$) | 146 | 154 | 178 | 205 | 130 | 292 | 725 | 988 |
| Free ammonia (as N) | .30 | .28 | .34 | .39 | 2.6 | 10.7 | 32 | 46 |
| Total Kjeldahl (as N) | .64 | .66 | 1.21 | .79 | 3.3 | 11.6 | 34 | 48 |
| Nitrite (as N) | .008 | .009 | .024 | .044 | .008 | .045 | .019 | .033 |
| Nitrate (as N) | .17 | .18 | .21 | .31 | .18 | .22 | .09 | .13 |
| Total phosphorus (as P) | .033 | .038 | .162 | .066 | .06 | .055 | .043 | .024 |
| Hardness (as $CaCO_3$) | 204 | 215 | 239 | 276 | 162 | 315 | 550 | 723 |
| Alkalinity (as $CaCO_3$) | 50 | 48 | 46 | 47 | 43 | 33 | 7.2 | 10.5 |
| Acidity (as $CaCO_3$) | 4 | 3.3 | 4.5 | 5.4 | 4.3 | 17 | 73 | 88 |
| Iron (as Fe) | 1.88 | 1.88 | 1.95 | 1.57 | 1.5 | 3.96 | 24 | 27.1 |
| Zinc (as Zn) | .54 | .57 | .70 | .76 | .43 | .69 | 1.52 | 1.39 |
| Copper (as Cu) | .023 | .02 | .02 | .025 | .03 | .05 | .07 | .19 |
| Sodium (as Na) | 7.2 | 7.9 | 8.8 | 12 | 5.4 | 16 | 31.4 | .38 |
| Potassium (as K) | 2.66 | 2.8 | 3.1 | 3.9 | 2.8 | 8.9 | 15.7 | 27.5 |
| Calcium (as Ca) | 65 | 68 | 74 | 97 | 47 | 94 | 147 | 191 |
| Magnesium (as Mg) | 10.3 | 9.3 | 10.3 | 8.3 | 8 | 15 | 16.5 | 24 |

Table 7. Seasonal and vertical changes in sulphate levels, Manitouwadge Lake and Mose Lake, 1970. Results are expressed as parts per million sulphates.

| Date | MANITOUWADGE LAKE | | | | MOSE LAKE | | | |
|---|---|---|---|---|---|---|---|---|
| | 0' | 10' | 20' | 30' | 0' | 10' | 20' | 30' |
| February 10 | 115 | 150 | 280 | 320 | 170 | 790 | 910 | 915 |
| March 18 | 173 | 220 | 300 | 470 | 140 | 810 | 910 | 1070 |
| April 15 | 190 | 230 | 280 | 340 | 160 | 725 | 500 | 850 |
| May 12 | 160 | 150 | 170 | 160 | 160 | 160 | 975 | 1125 |
| May 26 | 145 | 150 | 155 | 170 | 100 | 105 | 330 | 775 |
| June 12 | 120 | 120 | 120 | 140 | 90 | 100 | 880 | 1000 |
| June 23 | 140 | 136 | 144 | 164 | 100 | 96 | 750 | 1150 |
| July 18 | 139 | 124 | 129 | 139 | 105 | 106 | 690 | 940 |
| July 30 | 130 | 120 | 110 | 120 | 110 | 125 | 580 | 1130 |
| August 26 | 190 | 190 | 194 | 184 | 210 | 206 | 750 | 1300 |
| October 5 | 128 | 128 | 132 | 128 | 120 | 164 | 960 | 880 |
| November 2 | 124 | 124 | 124 | 124 | 100 | 116 | 460 | 720 |

differences from surface to bottom which prevents mixing or circulation of water. Conditions of meromictic stability, while uncommon, have been described for several lakes on the European Continent. One of these, Lake Ritom in Switzerland, is a classical example of a type of meromixis referred to as crenogenic (Hutcheson, 1957) which results from saline springs delivering dense sulphate-rich waters into the depths of the lake. In a similar manner, the dense sulphate-rich waters delivered to Mose Lake via Noranda Creek (1,100 ppm sulphates) have undoubtedly induced the condition of crenogenic meromixis.

The condition in Mose Lake has the effect of trapping and concentrating mining wastes in the bottom waters. This accounts for the gross chemical contamination detected in Mose Lake below the ten foot depth and explains as well why the chemical quality of Kaginu and Agonzon is better than would be expected.

## Acid Formation

Failure of pH adjustment at the point of discharge to prevent subsequent acid formation is a common problem associated with the handling of sulphuritic mining wastes. Considerable information is available in the literature describing the mechanisms involved in acid generation. Reference to Barnes (1968), Schmidt and Conn (1969) and Hawley and Shikaze (1971) is suggested for specific details of the chemistry involved. For the purposes of this report, the process can be described in the following simplified equations:

1) $2\ Fe\ S_2 + 7O_2 + 2H_2O \longrightarrow 2\ Fe\ SO_4 + 2H_2SO_4$

2) $4\ Fe\ SO_4 + 2H_2SO_4 + O_2 \longrightarrow 2\ Fe_2(SO_4)_3 + 2H_2O$

3) $Fe_2\ (SO_4)_3 + 6H_2O \longrightarrow 2\ Fe(OH)_3 + 3H_2SO_4$

All too frequently, total oxidation of soluble iron and sulphur species (along with other unoxidized substances) is not achieved at the point of discharge so that continued oxidation in the receiving water causes subsequent pH depression.

Evidence of acid generation in Mose Lake and to a lesser extent in Manitouwadge Lake is provided in Table 8 which compares the vertical and seasonal changes in alkalinity, acidity and pH of the two lakes. The pH value provides a measure of the hydrogen ion content of the water, while alkalinity readings measure the capacity of the water to neutralize hydrogen ions and the total acidity value is a measure of the total quantity of hydrogen ions which would be liberated during the oxidation and hydrolysis of the various cations in solution.

In Manitouwadge Lake, the low pH readings which occurred on April 15th, May 12th and July 30th suggest acid generation; however, this is probably not a critical situation in Manitouwadge Lake since the potential for hydrogen ion production, as measured by total acidity, is quite low and fairly good buffering would be expected on the basis of the alkalinity readings secured from the lake. In contrast, the waters of Mose Lake appear to be the site of considerable acid formation. Measurements of pH, alkalinity and acidity taken from the 20 and 30 foot depths in Mose Lake demonstrate that these waters have a high hydrogen ion content indicative of past acid formation, no reserve buffering capacity and a high potential for further hydrogen ion liberation.

Further indication that acid production was rampant in Mose Lake was obtained by bacteriological examination of water samples for the bacterium *Thiobacillus thiooxidans*,

an important biological agent in the oxidation of ferrous ions to ferric ions. On February 10, the surface waters of Mose Lake contained 11,000 of these bacteria per ml. On the same date, a much lower count of only 240 per ml. was recorded from a surface water sample taken from Manitouwadge Lake. The deeper waters of both lakes had much lower densities of T. thiooxidans than were present at the surface. At a depth of twenty feet, the respective counts in Manitouwadge Lake and Mose Lake were 43 and 2,100 bacteria per ml. Reductions in dissolved oxygen at the twenty foot depths would account for the lower numbers of T. thiooxidan, since the bacteria requires oxygen to live. On the sampling date, surface water levels of oxygen in Manitouwadge and Mose were 9 and 6 ppm respectively, whereas the corresponding levels were 5 and 3 ppm at the 20 foot depths.

Sediment Chemistry

Creek and lake sediments were sampled on several occasions in order to determine the extent of metal build-up and downstream transport. The results of sediment chemistry analyses are proved in Table 9.

Sediments from the uncontaminated reference waters contained only trace levels (<150 ppm) of zinc, copper and lead; on the other hand, these same metals were major components of the sediments of Mose and Manitouwadge lakes. From six sets of results, the respective maximum concentrations in Manitouwadge and Mose muds were: 8,860 and 7,120 ppm zinc, 1,234 and 3,480 ppm copper and 662 and 476 ppm lead. Lakes downstream from Manitouwadge and Mose had only slightly elevated levels of copper and lead in their sediments but high zinc occurred in all of these lakes, including Agonzon, the most remote body from the two sources of contaminants.

Apart from probable direct toxic effects on bottom

Table 8. Comparison of the vertical and season changes in Alkalinity, acidity and pH in Manitouwadge Lake and Mose Lake, 1970.

| Date | Alkalinity as $CaCO_3$ (ppm) | | | | Acidity as $CaCO_3$ (ppm) | | | | pH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0' | 10' | 20' | 30' | 0' | 10' | 20' | 30' | 0' | 10' | 20' | 30' |
| Manitouwadge Lake | | | | | | | | | | | | |
| Feb.10 | 47 | 46 | 44 | 39 | 5 | 5 | 5 | 5 | 7.3 | 7.5 | 7.8 | 7.4 |
| Mar.18 | 68 | 58 | 52 | 52 | 7 | 7 | 14 | 10 | 6.8 | 6.8 | 6.6 | 6.5 |
| Apr.15 | 64 | 54 | 28 | 42 | 4 | 6 | 6 | 6 | 6.3 | 6.1 | 6.6 | 6.4 |
| May 12 | 44 | 46 | 44 | 44 | 4 | 4 | 4 | 4 | 6.0 | 6.4 | 5.5 | 5.8 |
| May 26 | 42 | 42 | 42 | 42 | 4 | 2 | 2 | 4 | 6.7 | 6.8 | 6.8 | 6.8 |
| June 12 | 46 | 46 | 44 | 42 | 3 | 3 | 6 | 6 | | | | |
| June 23 | 46 | 46 | 46 | 46 | 2 | 2 | 4 | 4 | 6.7 | 6.7 | 6.8 | 6.8 |
| July 18 | 52 | 47 | 49 | 49 | 4 | 3 | 3 | 4 | | | | |
| July 30 | 52 | 47 | 47 | 47 | 1 | 1 | 2 | 8 | 5.9 | 6.2 | 6.3 | 6.4 |
| Aug. 26 | 54 | 55 | 54 | 58 | 2 | 3 | 3 | 9 | 7.7 | 7.7 | 7.8 | 7.3 |
| Oct. 5 | 50 | 53 | 48 | 53 | 3 | 2 | 2 | 2 | 7.6 | 7.7 | 7.6 | 7.7 |
| Nov. 2 | 32 | 36 | 50 | 54 | 3 | 2 | 3 | 3 | 7.3 | 7.4 | 7.4 | 7.4 |
| Mose Lake | | | | | | | | | | | | |
| Feb.10 | 42 | 2 | 4 | 4 | 11 | 34 | 169 | 154 | 7.0 | 5.2 | 4.9 | 5.1 |
| Mar.18 | 64 | 8 | 16 | 16 | 7 | 75 | 95 | 100 | 6.8 | 6.3 | 5.8 | 5.7 |
| Apr.15 | 82 | 6 | 20 | 24 | 6 | 67 | 49 | 63 | 6.2 | 5.6 | 5.8 | 5.6 |
| May 12 | 33 | 33 | 4 | 4 | 4 | 4 | 101 | 70 | 5.9 | 6.4 | 5.9 | 5.6 |
| May 26 | 37 | 37 | 6 | 0 | 4 | 4 | 16 | 78 | 6.0 | 6.6 | 5.8 | 6.0 |
| June 12 | 46 | 44 | 0 | 4 | 4 | 4 | 88 | 84 | | | | |
| June 23 | 49 | 46 | 2 | 2 | 2 | 2 | 73 | 74 | 7.0 | 7.0 | 5.6 | 5.1 |
| July 18 | 47 | 45 | 0 | 0 | 3 | 3 | 78 | 69 | | | | |
| July 30 | 43 | 43 | 0 | 4 | 1 | 1 | 44 | 86 | 6.5 | 6.5 | 6.0 | 5.7 |
| Aug. 26 | 45 | 44 | 0 | 12 | 5 | 4 | 22 | 106 | 7.5 | 7.6 | 4.8 | 5.6 |
| Oct. 5 | 46 | 42 | 22 | 18 | 2 | 2 | 109 | 110 | 7.5 | 7.6 | 5.7 | 3.9 |
| Nov. 2 | 64 | 46 | 12 | 38 | 3 | 5 | 33 | 66 | 7.4 | 7.3 | 6.2 | 6.2 |

Table 9. Results of chemical analyses performed on sediment samples collected from streams and lakes of the Manitouwadge Chain during 1970. Values given are average for the number of samples indicated.

| | No. of Samples | % Loss on Ignition | Zinc as Zn (ppm) | Copper as Cu (ppm) | Lead as Pb (ppm) | Manganese as Mn (ppm) | Iron as Fe (%) ** |
|---|---|---|---|---|---|---|---|
| Wowun Creek* | 1 | 11.8 | <150 | <150 | <150 | <150 | 1.06 |
| Willroy Creek | 2 | 19.6 | 680 | 700 | 160 | 323 | 3.41 |
| Fox Creek | 1 | 26.0 | 4600 | 1344 | 252 | 364 | 7.75 |
| Noranda Creek | 1 | 22.4 | 868 | 552 | <150 | 170 | 7.22 |
| Wowun Lake* | 2 | 13.9 | <150 | <150 | <150 | 307 | 2.27 |
| Morley Lake* | 1 | 34.7 | <150 | <150 | <150 | 258 | 1.48 |
| Manitouwadge Lake (mouth of Willroy Cr.) | 2 | 15.9 | 3000 | 564 | <150 | 520 | 2.53 |
| Manitouwadge Lake (Fox Bay) | 2 | 30.1 | 7080 | 2313 | 247 | 366 | 12.70 |
| Manitouwadge Lake | 6 | 19.6 | 4505 | 791 | <150 | 417 | 3.0 |
| Little Manitouwadge Lake | 4 | 15.9 | 675 | <150 | <150 | 303 | 2.31 |
| Little Mose Lake | 4 | 16.5 | 1660 | 167 | <150 | 272 | 2.48 |
| Mose Lake | 6 | 24.0 | 3985 | 1955 | 164 | 343 | 5.52 |
| Kaginu Lake | 4 | 21.3 | 1663 | 222 | <150 | 347 | 2.87 |
| Agonzon Lake | 4 | 23.5 | 1443 | 156 | <150 | 422 | 2.82 |

* Control creek and lakes
** 1% is equivalent to 10,000 ppm.

dwelling organisms, an even greater concern is the potential for these conservative materials to become remobilized and released back into the water.

Indication of metals exchange through the sludge water interface can be noted in Table 10 which lists the specific levels of zinc and copper in sediments of Manitouwadge Lake and Mose Lake on six sampling dates. These data show lower concentrations of zinc and copper in the sediments of both lakes during March and April than were present in May, June and July. Copper and zinc values appear to be released from the lake sediments during periods of ice cover (i.e. March and April) and deposited to the lake muds during the ice-free months.

## Fish Flesh Chemistry

During July, staff of the Department of Lands and Forests carried out a minimal fish survey on the study lakes to secure fish samples for metals analyses. Unfortunately, a power failure which affected storage facilities resulted in the loss of a portion of the samples before analyses had been completed. Liver samples from some of the reference lake specimens were amongst the material lost. Results of analyses completed before the power failure occurred are provided in Table I of the Appendix.

Walleye from the reference lake Wowun contained mercury levels slightly higher than the 0.5 ppm safety level for consumption as did a single walleye from Mose Lake and two perch taken from Agonzon Lake. In general, however, the mercury content of fish from the study waters was low and apparently uninfluenced by the mining operations.

Unlike mercury which tends to concentrate to the top of the food chain, zinc and copper values were highest in whitefish which are bottom feeders and in cisco which feed

Table 10. Zinc and copper in the sediments of Manitouwadge Lake and Mose Lake, March to July, 1970.

| | MANITOUWADGE LAKE | | MOSE LAKE | |
|---|---|---|---|---|
| | Zinc as Zn (ppm) | Copper as Cu (ppm) | Zinc as Zn (ppm) | Copper as Cu (ppm) |
| March 18 | 1,420 | 364 | 1,380 | 330 |
| April 15 | 1,540 | 426 | 1,268 | 1,200 |
| May 13 | 4,600 | 984 | 4,200 | 3,480 |
| May 26 | 6,300 | 1,234 | 5,940 | 4,200 |
| June 23 | 4,280 | 708 | 7,120 | 240 |
| July 30 | 8,860 | 1,034 | 4,000 | 2,280 |

on planktonic organisms; values were several orders of magnitude lower in walleye, pike and perch, all of which are predaceous.

Another factor of significance shown by the data is that both zinc and copper are concentrated in the liver of fish whereas the values of these metals remain fairly constant in the muscle. Zinc values reached extremes of 900 ppm in the livers of whitefish and cisco. Copper was either absent or only present in trace quantities in pike flesh.

Trapping of zinc and copper in the liver undoubtedly acts to the detriment of the fish; however, consumption of these fish would probably not present a health hazard.

Owing to the loss of liver samples from the reference lake, no clarification can be provided at this time of the relationship, if any, which exists between the mining operations at Manitouwadge and the extreme metals content of liver samples of whitefish and cisco taken from Manitouwadge, Mose, Kaginu and Agonzon lakes. Additional samples will be obtained from Wowun Lake to investigate this relationship further.

## Bottom Fauna

Lakes of Northern Ontario are inherently limited both with respect to variety and abundance of macroinvertebrate bottom fauna. This factor poses no great difficulty in the investigation of organic pollution which tends to restrict variety but increase the numbers of organisms in the affected community. However, inorganic pollution such as that resulting from acid-mine wastes has a restrictive influence on the bottom fauna community both with respect to variety and abundance so that the net effect of acid-mine

pollution is to impose further restrictions on an inherently unproductive community.

Figure 2 depicts the lake to lake distribution and densities of bottom fauna collected from the Manitouwadge Chain of Lakes during 1970. These data are provided in summarized form in Table 12 below.

Table 12. Variety and abundance of bottom fauna collected from eight lakes of the Manitouwadge Chain, 1970.

| Lake | Variety (No.of Taxa) | Density (No.of Organisms/ft.$^2$) |
|---|---|---|
| Wowun | 7 | 37 |
| Morley | 8 | 29 |
| Manitouwadge | 5 | 12 |
| Little Manitouwadge | 5 | 16 |
| Little Mose | 8 | 25 |
| Mose | 2 | $<1$ |
| Kaginu | 6 | 17 |
| Agonzon | 4 | 26 |

Mose Lake provides a spectacular example of severe acid-mine pollution and its effect on benthic production. Eleven of fifteen sediment samples taken from Mose Lake were void of life and the yield from the remaining four samples was a mere five specimens, three of which were phantom midges of the genus *Chaoborus*, a planktonic form which in all likelihood were taken by the dredge on its descent through the epilimnion to the lake bottom. Assuming this to be true, then only two individuals, both midges of the family Tendipedidae, were present in 8.1 ft.$^2$ (fifteen

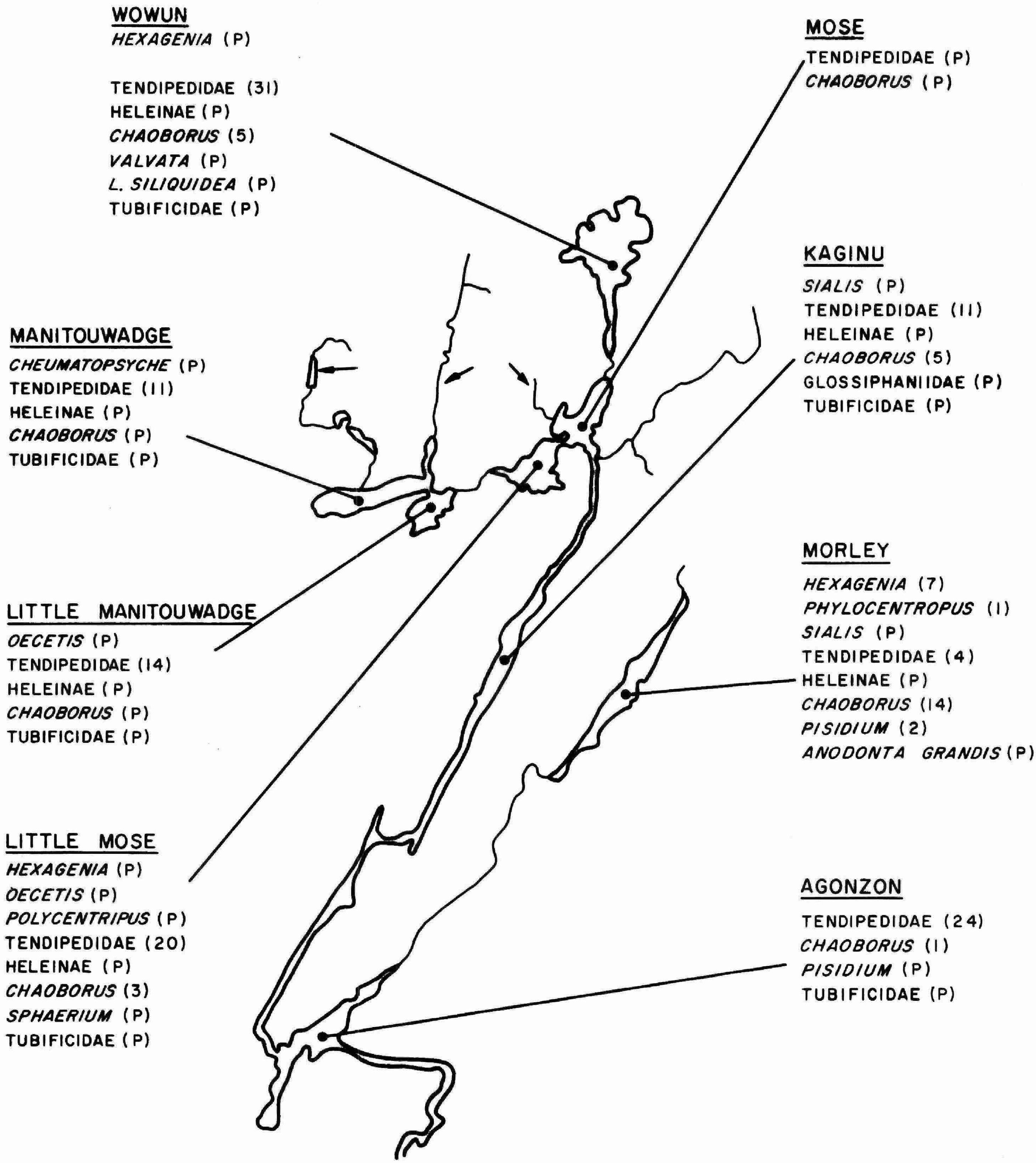


FIG 2. DISTRIBUTION AND ABUNDANCE OF MACROIN VERTEBRATES COLLECTED FROM THE MANITOUWADGE CHAIN OF LAKES, 1970. NUMBERS IN BRACKETS INDICATE DENSITY OF THE ORGANISM PER $FT^2$. "P" SIGNIFIES ORGANISM PRESENT IN DENSITY OF LESS THAN ONE PER $FT^2$.

Ekman dredge samples) of Mose Lake sediments. The same effort on the reference lakes Wowun and Morley produced respective yields of 7 and 8 taxa and densities of 37 and 29 organisms per $ft.^2$.

Manitouwadge Lake, which contains a greater volume of water than Mose Lake and receives a lesser volume of mine wastes, yielded five taxa of macroinvertebrates and a density of 12 organisms per $ft.^2$. While considerably healthier than the Mose Lake community, this still represents an impoverished community in comparison with those of the reference lakes.

Little Manitouwadge Lake contained a community comparable to that of Manitouwadge Lake, its source, except for a slightly higher standing crop of 16 organisms per $ft.^2$. Both of these lakes contained taxa which Parsons (1968) and Katz (1969) found to exhibit tolerance to acid-mine pollution and neither lake yielded specimens of mayflies Hexagenia sp. or the unionids Lampsalis siliquoidea and Anadonta grandis which were listed by the same authors as being intolerant of acidic mine wastes. All three of these forms were present in the control lakes Wowun and Morley.

The benthos of Little Mose Lake, which is situated downstream from Little Manitouwadge Lake, provides evidence of improved water quality. The bottom fauna community of Little Mose Lake compared favourably with the control lakes both with respect to variety and number of organisms present. Mayflies of the genus Hexagenia were present in Little Mose Lake but no unionid clams were taken.

Kaginu Lake, downstream from Mose Lake, contained a bottom fauna association similar in most respects to that of moderately polluted Manitouwadge Lake. Agonzon, the final

downstream lake, contained a low number of taxa but produced a density of 26 organisms per ft.$^2$ which is close to the density found in the reference lakes. Hexagenia and unionid clams were absent from both Kaginu and Agonzon.

The status of unionid clams in waters affected by mine wastes is such that it warrants further comment. At least two species of unionids are indigenous to the Black River. Anadonta grandis occurred in Morley Lake and extensive beds containing Lampsalis siliquoidea were observed in Wowun Lake and Wowun Creek. No live clams were observed nor taken from any of the six lakes situated below the mining industry. Empty shells of L. siliquoidea were observed in Mose Lake.

Conroy (1969), in reporting the findings of a similar study on the Serpent River system of northern Ontario, cited elimination of the unionid clams as being the most pronounced influence of acid-mine wastes on lake macroinvertebrate communities. Similarly, Parsons' (1968) studies on Cedar Creek in Missouri and the work of Katz (1969) on waters of the Appalachia demonstrate the extreme sensitivity of unionids to acid-mine pollution.

The susceptibility of clams (Unionidae) to acidic mine wastes can be attributed to a number of factors. First and probably most significant, clams are noted for their capacity to concentrate metals, a factor which would eventually prove lethal to the organism. Another factor of significance in the Manitouwadge Lakes is that of elevated potassium levels. Inlay (1969) has demonstrated through laboratory studies and field observations

that survival of unionids would be marginal in waters containing 4 ppm potassium and impossible at concentrations of 7 ppm or greater. Respective maximums from the polluted lakes, Manitouwadge and Mose were 6.1 and 35 ppm potassium, while all measurements from the reference lakes, Morley and Wowun, were less than 1 ppm.

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# APPENDIX

Table 1. Concentrations of Hg, Cu and Zn in muscles and livers of fishes taken from Manitouwadge, Mose, Kaginu, Agonzon and Wowun lakes, July, 1970.

Table I. Concentrations of Hg, Cu and Zn in muscles and livers of fishes taken from Manitouwadge, Mose, Kaginu, Agonzon and Wowun lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Wowun | Cisco | 22 | 135 | Muscle | .13 | .08 | 22.6 |
| | | 18 | 90 | " | .14 | .18 | 19 |
| | | 18.5 | 95 | " | - | .3 | 23.7 |
| | | 21 | 120 | " | .06 | .09 | 17.2 |
| | Sucker | 40.5 | 820 | " | .08 | .3 | 3.8 |
| | | 37 | 630 | " | .08 | .5 | 5.3 |
| | | 35 | 550 | ' | .05 | .6 | 7.0 |
| | | 31 | 340 | " | .05 | .3 | 6.2 |
| | | 36 | 610 | " | .07 | - | - |
| | Perch | 25.5 | 230 | " | .41 | .2 | 4.7 |
| | | 25 | 250 | " | .26 | .1 | 5.7 |
| | | 27.5 | 320 | " | .17 | .3 | 6.0 |
| | Pike | 50 | 825 | " | .14 | 0.0 | 5.6 |
| | | 48 | 805 | " | .11 | 0.0 | 3.7 |
| | | 64 | 1550 | " | .31 | .26 | 3.7 |
| | | 45 | 705 | " | .20 | .21 | 3.9 |
| | Walleye | 37 | 515 | " | .63 | 0.0 | 3.6 |
| | | 40 | 980 | " | .68 | 0.0 | 4.0 |
| | | 38.5 | 685 | " | .79 | 0.0 | 3.7 |
| | | 41 | 850 | " | .49 | 0.0 | 3.5 |
| | | 37 | 515 | Liver | | .47 | 19.7 |
| | | 40 | 980 | " | | 2.52 | 16.3 |
| | | 38.5 | 685 | " | | 1.29 | 16.6 |
| | | 41 | 850 | " | | 5.26 | 20.5 |

cont'd

Table I. (cont'd) Concentrations of Hg, Cu and Zn in Muscles and livers of fishes taken from Manitouwadge, Mose, Kaginu, Agonzon and Wowun lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Manitouwadge | Whitefish | 34.5 | 530 | Muscle | .06 | 0.9 | 13.1 |
| | | 34.5 | 530 | Liver | | 41 | 900 |
| | Sucker | 35.5 | 570 | Muscle | .06 | 0.3 | 6.0 |
| | | 31.5 | 430 | " | .06 | 0.5 | 4.7 |
| | | 24.5 | 170 | " | .06 | 0.3 | 6.1 |
| | | 28.5 | 280 | " | .08 | 0.6 | 5.4 |
| | | 26.5 | 210 | " | .06 | 0.4 | 5.2 |
| | Pike | 26 | 105 | " | .05 | 0.4 | 12.8 |
| | Walleye | 44.5 | 1010 | " | .06 | 0.0 | 4.8 |
| | | 37.5 | 630 | " | .37 | 0.0 | 5.1 |
| | | 43 | 1190 | " | .05 | 0.1 | 5.3 |
| | | 50.5 | 1360 | " | .31 | 0.0 | 4.7 |
| | | 44.5 | 1010 | Liver | | 7 | 32 |
| | | 37.5 | 630 | " | | 2.5 | 27 |
| | | 43 | 1190 | " | | 4.2 | 28 |
| | | 50.5 | 1360 | " | | 29 | 42 |
| Mose | Whitefish | 20.5 | 150 | Muscle | 0.012 | 0.0 | 9.5 |
| | | 31 | 390 | " | 0.045 | 0.0 | 5.6 |
| | | 21 | 165 | " | 0.012 | 0.0 | 8.0 |
| | | 37 | 740 | " | 0.058 | 1.4 | 5.0 |
| | | 36 | 740 | " | 0.037 | 0.0 | 3.7 |
| | | 20.5 | 150 | Liver | | 18.2 | 261 |

cont'd...

Table I. (cont'd) Concentrations of Hg, Cu and Zn in Muscles and livers of fishes taken from Manitouwadge, Mose, Kaginu, Agonzon and Wowun lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Mose | Whitefish | 31 | 390 | Liver | | 11.2 | 546 |
| | | 21 | 165 | " | | 5.8 | 399 |
| | | 37 | 740 | " | | 33.2 | 418 |
| | | 36 | 740 | " | | 19.3 | 224 |
| | Sucker | 38 | 690 | Muscle | .04 | 0.0 | 3.6 |
| | | 40.5 | 670 | " | .08 | 0.0 | 3.2 |
| | | 42 | 850 | " | .26 | 0.0 | 2.9 |
| | | 36 | 980 | " | .11 | 0.0 | 2.6 |
| | | 38 | 670 | " | .08 | 0.0 | 3.7 |
| | Pike | 41 | 550 | " | .06 | 0.0 | 4.4 |
| | | 40.5 | 520 | " | .07 | 0.0 | 4.1 |
| | | 41 | 550 | Liver | | 37.1 | 46.8 |
| | | 40.5 | 520 | " | | 36.8 | 36.6 |
| | Walleye | 36 | 635 | Muscle | 0.10 | 0.0 | 4.0 |
| | | 42 | 1035 | " | 0.52 | 0.0 | 3.8 |
| | | 36 | 635 | Liver | | 3.2 | 19 |
| | | 42 | 1035 | " | | 4.2 | 18.9 |
| Kaginu | Sucker | 35 | 610 | Muscle | .06 | .25 | 3.5 |
| | | 30 | 365 | " | .04 | .39 | 3.6 |
| | | 37 | 740 | " | .01 | .35 | 3.6 |
| | | 43 | 940 | " | .08 | .41 | 4.6 |
| | | 42 | 890 | " | .01 | .27 | 2.9 |

cont'd..

Table I. (cont'd) Concentrations of Hg, Cu and Zn in Muscles and livers of fishes taken from Manitouwadge, Mose Kaginu, Agonzon and Wowun lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Kaginu | Pike | 45 | 560 | Muscle | .06 | 0.0 | 3.6 |
| | | 45 | 540 | " | .06 | 0.0 | 4.6 |
| | | 45 | 660 | " | - | 0.2 | 3.1 |
| | | 47 | 690 | " | .09 | 0.28 | 7.12 |
| | | 46.5 | 670 | " | .10 | 0.22 | 3.2 |
| | Walleye | 32 | 425 | " | .04 | 0.0 | 3.8 |
| | | 26 | 180 | " | .06 | 0.0 | 11.6 |
| | | 46 | 1010 | " | .18 | .11 | 2.8 |
| | | 33 | 440 | " | .07 | .42 | 3.94 |
| | | 43 | 975 | " | .15 | 0.0 | 2.15 |
| Agonzon | Cisco | 27 | 265 | " | .11 | 0.0 | 25.6 |
| | | 27 | 260 | " | .10 | 0.0 | 13.5 |
| | | 26 | 190 | " | .20 | 0.0 | 25.8 |
| | | 27.5 | 260 | " | .13 | 0.0 | 21.0 |
| | | 25 | 260 | " | .05 | 0.0 | 18.5 |
| | | 27 | 280 | " | .09 | 0.0 | 8.9 |
| | | 27 | 265 | Liver | | 6.5 | 900 |
| | | 27 | 260 | " | | 3.7 | 61 |
| | | 26 | 190 | " | | 0.0 | 930 |
| | | 27.5 | 260 | " | | 3.5 | 790 |
| | | 25 | 260 | " | | 1.8 | 820 |
| | | 27 | 280 | " | | 1.9 | 560 |

cont'd...

Table I. (cont'd) Concentrations of Hg, Cu and Zn in Muscles and livers of fishes taken from Manitouwadge, Mose, Maginu, Agonzon and Wowun lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Agonzon | Sucker | 36.5 | 790 | Muscle | .25 | 0.0 | 4.2 |
| | | 40 | 750 | " | .16 | 0.0 | 4.0 |
| | | 30 | 330 | " | .05 | 0.0 | 7.5 |
| | | 33 | 500 | " | .05 | 0.0 | 7.2 |
| | | 29.5 | 330 | " | .05 | 0.0 | 6.6 |
| | | 36.5 | 790 | Liver | | 5.2 | 21 |
| | Perch | 29.5 | 330 | Muscle | .70 | 0.0 | 5.8 |
| | | 23 | 210 | " | .29 | 0.0 | 7.1 |
| | | 28 | 320 | " | .66 | 0.0 | 2.0 |
| | | 24 | 170 | " | .18 | 0.0 | 5.4 |
| | | 24 | 150 | " | .35 | 0.0 | 7.5 |
| | | 28 | 320 | Liver | | 9.7 | 68 |
| | Pike | 48 | 659 | Muscle | .21 | 0.0 | 4.7 |
| | | 44 | 570 | " | .14 | 0.0 | 5.3 |
| | | 62 | 1500 | " | .36 | 0.0 | 4.5 |
| | | 49 | 760 | Liver | | 21.6 | 43.4 |
| | | 44 | 570 | " | | 16.9 | 77.4 |
| | | 62 | 1500 | " | | 5.5 | 52.0 |
| | Walleye | 40 | 680 | Muscle | .18 | 0.0 | 16.4 |
| | | 37 | 560 | " | .11 | 0.34 | 3.6 |
| | | 28 | 250 | " | .07 | 0.0 | 4.0 |
| | | 33 | 410 | " | .09 | 0.0 | 3.8 |
| | | 35 | 490 | " | .14 | 0.0 | 4.0 |

cont'd.....

Table I. (cont'd) Concentrations of Hg, Cu and Zn in Muscles and livers of fishes taken from Manitouwadge, Mose, Maginu, Agonzon and Wowun Lakes, July, 1970.

| Lake | Species | Length (cms) | Weight (gms) | Sample | Hg (ppm) | Cu (ppm) | Zn (ppm) |
|---|---|---|---|---|---|---|---|
| Agonzon | Walleye | 33 | 395 | Muscle | .10 | 0.0 | 3.4 |
| | | 40 | 680 | Liver | | 1.8 | 16.7 |
| | | 37 | 560 | " | | 1.5 | 18.5 |
| | | 28 | 250 | " | | 0.0 | 24.8 |
| | | 33 | 410 | " | | 0.0 | 21.0 |
| | | 35 | 490 | " | | 1.8 | 18.7 |
| | | 33 | 395 | " | | 0.0 | 19.8 |

ABATEMENT ACTIONS TAKEN AND PROPOSED IN THE MANITOUWADGE AREA

In recent years, it has been recognized that wastewaters from the mining and milling of sulphidic base metal ore such as that at Manitouwadge can cause serious water quality impairment. The main potential sources of the water contaminants causing the impairment are the wastewaters from the tailings areas and mines and the seepage waters from the tailings area dykes. When environmental problems associated with such operations are encountered, a basic approach is being taken to eliminate or minimize these problems. This approach includes recycling tailings decant and mine waters to the maximum extent possible and treating that portion which cannot be recycled, before it is discharged. It also includes the collection and return to the tailings area, after treatment, of any seepage waters from the tailings area dykes.

Water quality impairment had been recognized in the Manitouwadge area in a general way as a result of earlier investigations by staff of the Department of Lands and Forests and this Ministry's Industrial Wastes Branch. As a result of these investigations, the major study which is the subject of the present report, was undertaken and, in addition, concrete corrective measures have been taken by the two companies concerned and others are in progress or are in the planning stage.

The report recommends that to correct the adverse environmental effects demonstrated in the study, it will be necessary to eliminate ammonia losses (applicable only to Noranda Mines Limited effluents), control metal losses to

essentially background concentrations, prevent further discharge of oxidizable sulphuritic wastes, provide effluent pH control and substantially reduce the loading of sulphates and other dissolved solids discharged. The corrective measures taken by the mining companies in recent years which are pertinent to these recommendations and to the basic corrective approach are:

Noranda Mines Limited

(1) Lime has been added to the tailings to partially control the acid condition in the tailings area decant (i.e., pH control).

(2) A system to collect tailings area dyke seepage water and to return it to the tailings area after treatment has been installed.

(3) A system has been installed to recycle all mine wastewaters to the mill process with any excess being discharged to the tailings area.

(4) A conceptual plan has been prepared to recycle all wastewaters to the maximum extent possible and treat the excess before discharge.

(5) Design of the recycle system envisaged in this conceptual plan is proceeding with the objective of installation by the end of 1972.

Willroy Mines Limited

(1) An integral part of the water system at this mill has been the recycle of mine wastewaters with overflow to the tailings area.

(2) The tailings area capacity has been increased to provide

conditions suitable for future recycle and treatment of tailings area wastewater.

(3) Action has been taken to reduce tailings area dyke seepage and to provide for its detention and monitoring in preparation for future recycle to the tailings area after treatment.

(4) A Company consultant has completed investigations to confirm the suitability of wastewaters for recycle to the mill process.

(5) Preparation has been made to rehabilitate a portion of the tailings area and eliminate it as a source of contaminant loss.

In addition to the actions already taken, both Companies are working on future plans. Willroy Mines Limited is preparing a proposal for a continuation of its present abatement program which, it is expected, will include full recycle of wastewaters and treatment of any excess before discharge.

Noranda Mines Limited has begun investigations of problems it expects will be encountered when recycle waters are used in its mill process after completion of the recycle system. As a result of these investigations and initial experience with the recycle system, it expects to submit a proposal for the treatment of excess recycle system water early in 1973. The treatment facilities would be installed in 1973.

The need to eliminate ammonia losses by effluent

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treatment or by replacing it in the process by an acceptable alternative material has been discussed with Noranda Mines Limited. However, because a survey of available current technology disclosed that at present a viable method for the removal of ammonia from wastewaters under conditions at this location did not exist and because of the extremely high operating costs involved in changing to an alternative, the Company will determine the effect of its recycle/treatment program on ammonia losses and investigate treatment methods for ammonia removal before a final decision on the resolution of this aspect of the problem is made.

The present and projected corrective programs at these mines to recycle wastewaters to the maximum extent possible and treat the balance before discharge will ensure that the pH control recommended in the report will be achieved. It will also substantially reduce the losses of metals and oxidizable sulphuritic wastes mentioned in these recommendations. It may also reduce the ammonia, sulphate and other dissolved solids losses but to a much smaller degree.

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